האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

UNSEEN BUT NOT UNSOLVED: DOING ARITHMETIC NON-CONSCIOUSLY

By

ASAEL Y. SKLAR and RAN R. HASSIN

Discussion Paper # 576 June 2011

מרכז לחקר הרציונליות

CENTER FOR THE STUDY
OF RATIONALITY

Feldman Building, Givat-Ram, 91904 Jerusalem, Israel
PHONE: [972]-2-6584135 FAX: [972]-2-6513681
E-MAIL: ratio@math.huji.ac.il
URL: http://www.ratio.huji.ac.il/

Unseen But not Unsolved:

Doing Arithmetic Non-Consciously

Asael Y. Sklar [a]

Ran R. Hassin [a,b 1],*

UNDER REVIEW, PLS DON'T QUOTE WITHOUT PERMISSION

a. Psychology Department

The Hebrew University

Jerusalem, Israel

b. The Center for the Study of Rationality

The Hebrew University

Jerusalem, Israel

1. To whom correspondence should be addressed

Abstract

The modal view in the cognitive sciences holds that consciousness is necessary for abstract, symbolic and rule-following computations. Hence, mathematical thinking in general, and doing arithmetic more specifically, are widely believed to require consciousness. In the current paper we use continuous flash suppression to expose participants to extremely long-duration (up to 2000 milliseconds) subliminal arithmetic equations. The results of three experiments show that the equations were solved without ever reaching consciousness. In other words, they show that arithmetic can be done unconsciously. These findings imply that the modal view of the unconscious needs to be significantly updated, to include symbolic processes that were heretofore considered to be uniquely conscious.

Understanding the limitations of unconscious processes in high level cognition, thereby discovering possible functions of consciousness, stands at the center of much research in the cognitive sciences. One conclusion that clearly emerges from this research is that many processes that seemed to require consciousness (such as goal pursuit, working memory and self control) can occur outside of conscious awareness (e.g., Bargh, 2007; Dijksterhuis & Aarts, 2010; Hassin, Uleman, & Bargh 2005). Yet, language and mathematics – two of the highlights of human culture – are widely believed to be intimately associated with consciousness (Baumeister & Masicampo 2010; Dijksterhuis, 2004; Morwedge & Kahneman, 2010; Winkielman & Schooler, 2008). This view is causal in nature: consciousness is seen as a prerequisite for the development of abstract symbolic systems like language and mathematics. In more general terms, then, sequential rule-following manipulations of abstract symbols are still believed to lie outside the capabilities of the human unconscious. In the current paper we present three experiments that strongly suggest that this boundary should be redrawn, because arithmetic calculations can occur non-consciously.

Varieties of Subliminal Semantics

Numbers

The semantic processing of numbers, and digit position coding, have been shown to occur even with subliminally presented stimuli. Given the volume of this literature, its review lies beyond the scope of the current paper. We will, however, review key findings that are central for the current claim (we refer interested readers to two thoughtful reviews: Kouider & Dehaene, 2007, Van den Bussche, 2009).

Most of the evidence for semantic processing of numbers was gathered in congruency paradigms. Thus, for example, participants are asked to categorize consciously visible numbers as larger or smaller than 5, while subliminal primes that precede these targets are either larger or smaller than 5. When, for example, the masked prime '*2*' precedes a visible '*3*' the two activated answer-tendencies are congruent (*smaller than five)*; when the masked prime is '*7*', however, they are incongruent. Data gathered in experiments of this sort consistently show a reliable congruency effect, thus suggesting non-conscious semantic processing of numbers (see Dehaene et al. 1998; Greenwald, Abrams, Naccache & Dehaene, 2003; Naccache

& Dehaene, 2001). These findings were greeted with skepticism (e.g., Abrams & Greenwald, 2000; Damian, 2001), yet subsequent research convincingly showed that single- as well as two-digit numbers can be processed when presented subliminally (Bahrami et al 2010; Garcia-Ozra and Perea 2011; Kouider & Dehaene, 2009).

Operations

In a related literature it has been established that simple arithmetic can occur *automatically*, that is – without intention and relatively effortlessly (e.g. Galfano, Rusconi, & Umilta, 2003; Zbrodoff & Logan 1986; for a review see, e.g., Ashcraft 1992, 1995). The question of *awareness* in automatic arithmetic has only been addressed recently, however. In one such paper, García-Orza, Damas-López, Matas, and Rodríguez (2009) presented participants with subliminal equations that consisted of two single digits and an operator, and examined the effects of these equations on explicit targets. The results showed that responses in congruent trials (e.g., target '*6'* follows the subliminal '*2 x 3'*) were faster than in incongruent ones. Garcia-Ozra et al. (2009) conclude that their results show "direct retrieval" of solutions (p. 479) – a strategy that falls short of *solving* arithmetic equations. Given the simplicity of the equations they used, this cautious conclusion may be warranted. Yet, the results are also consistent with the idea put forward here of *non-conscious arithmetic computations*, and we hence find them encouraging.

Beyond Numbers and Operations

Attempts to show more complex manipulations of abstract symbols, such as semantically processing the meaning of *two*-word expressions (e.g., green bread), or processing simple negations (e.g., not X), have consistently failed with subliminal or even briefly presented supraliminal stimuli (Deutsch, Gawronski, Strack, 2006; Greenwald, 1992; Greenwald & Liu, 1985).

The successes associated with "simple" subliminal semantic priming, and the failure of more complex subliminal processing, are partly responsible for the widely accepted view which holds that consciousness is inherent to sequential and rule following manipulations of abstract symbols (e.g., Evans, 2008). A prime example for a process of this sort is arithmetic calculation. Numbers are culturally-defined arbitrary symbols that stand for (represent) abstract concepts. Arithmetic is a series of sequential, rule following computations defined over these symbols. And indeed, scientists from various corners of the cognitive sciences converge in suggesting that arithmetic lies outside of the scope of unconscious processes (e.g., Baumeister & Masicapmo, 2010; Dijksterhuis, 2004; Morwedge and Kahneman, 2010).

The Current Studies

We report 3 experiments that use priming to investigate non-conscious arithmetic. In all experiments we monocularly presented an equation (e.g., *6-1-2=*), while simultaneously presenting rapidly-changing visual noise patches to the other eye, on the homolog retinal location (see Fig. 1). This technique – Continuous Flash Suppression (CFS) – was recently developed by Tsuchiya and Koch (2005), and it leads to the suppression from awareness of the more stable stimuli. In the current experiments the arithmetic equations were more stable, and therefore participants remained unaware of them.

Following the presentation of an equation (henceforth: the prime) a visible target stimulus was presented, and participants were asked to respond by either naming it (Experiments 1 and 2; Fig. 1) or verifying its correctness (Experiment 3). In each trial of the *congruent* conditions, the result of the prime was identical to the target stimulus. In the *incongruent* conditions, it was not. We expected to find an advantage in performance in the congruent conditions. Such an advantage would indicate that the result of the primed equation was mentally accessed (Jackson & Coney, 2005), that is – that the equation had been solved.

Objective and Subjective Measures

Lack of awareness to stimuli was confirmed via two strict criteria. First, at the end of each experiment participants completed an objective test, in which they repeatedly made two-alternative forced choice judgments regarding the subliminal stimuli (Cheesman & Merikle, 1984; Merikle & Reingold, 1992). Next, participants completed a subjective measure, in which they answered explicit questions about the nature of the stimuli and the experiment (Bargh & Chartrand, 2000). We exclude from analyses participants who indicate awareness of the non-conscious stimuli on either test.

A Pilot Study of Arithmetic Effortfulness

Whereas solutions to two digit arithmetic equations often automatically present themselves to consciousness, and thus feel "computation-less", solutions to *three* single digit equations feel effortful, "computational", and conscious. In order to examine this intuition we conducted a pilot in which addition and subtraction equations, of either two or three single-digit numbers, were presented one at a time on a computer screen, intermixed with fillers. Participants in the study, 21 Hebrew university students, were asked to say out-loud the solution as quickly as they could, and voice onset was recorded.

There were three major findings from this pilot that are important for the current purposes. First, even two digit equations take rather long to solve in this paradigm (M=1087.94 ms, SD=167.87), which may suggest that they are not as effortless and computationless as previously thought. Second, in three-digit equations subtraction takes longer than addition (M=2167.78 ms, SD= 494.33 and M=1795.01 ms, SD=274.36, respectively), $t(20)=3.69$, $p=0.001$, and is hence likely to be more difficult. Lastly, three digit equations take considerably longer to solve than two digit equations (M=1981.40 ms, SD= 437.61, and M=1087.94 ms, SD=167.87, respectively), $F(1,20)=303.71$, $p=0.001$, indicating that they are considerably more difficult. We thus chose to begin our investigation with three digit equations.

Experiment 1

In the first experiment participants were presented with CFS-suppressed three single-digit equations (e.g. 2+3+5=; 9-3-4=; see table S1 in the supporting information available on-line for a complete list). The target stimuli consisted of numbers that participants were asked to pronounce (e.g., 10), and voice onset time was the dependent variable. In order to assess the temporal dynamics of the process there were three between-subject conditions of presentation duration, selected on the basis of the explicit solution times in the pilot.

Method

Participants and design.

62 (49 female) Hebrew university students (M_{age}=21.94, SD=2.48) were randomly allocated to the conditions of a 3 (Duration: 1400 ms vs. 1700 ms vs. 2000 ms; between subjects) x 2 (Operation: Addition vs. Subtraction) x 2 (Congruence: Congruent vs. Incongruent) mixed design.

Stimuli.

Each priming equation was matched with one congruent and one incongruent target number, and was presented only once to each subject, either as a congruent prime or as an incongruent one (counterbalanced between participants). Stimuli were selected such that (a) the target number could not be identical to any of the numbers comprising the equations; (b) the target number could not constitute a partial solution of the equations, and (c) The average numeric distance between the digits in the equations and their targets was the same for congruent and incongruent conditions. These constraints resulted in the uneven number of stimuli between operands: 80 addition equations and 74 subtraction equations.

Procedure.

Participants sat in front of a CRT screen (~30 centimeters), and were then fitted with a mirror stereoscope, such that each mirror reflected a different part of the screen. The mirrors were adjusted to align the visual fields.

Then, participants were told that the experiment had two different tasks: *equation solving* and *number naming*. They were further told that the experiment will begin with the *solving* task, move to the *naming* task, and then go back to the *solving* task. The *naming* task was comprised of the experimental blocks. Participants were asked to pronounce numbers (the targets) that appeared on the screen as quickly as possible. Targets were preceded by nonconscious primes of which participants had not been informed. The *solving* task was added to make the solution of arithmetic equations context-appropriate. In this task equations were supraliminally presented, and participants were asked to state their solutions to the microphone. There were no primes, and equations presented during the *solving* task were not repeated as primes in the *naming* task.

Each experimental trial began with the monocular presentation of a prime equation, presented in 12pt Arial font, to the participant`s non-dominant eye. At the same time a visual noise stimuli were presented monocularly to the contralateral eye. The latter were comprised of three rows of randomly-chosen Hebrew letters, presented in 13pt Arial font. The noise screens altered at a rate of 10 hz. The stimuli were presented for either 1400 milliseconds, or 1700 ms or 2,000 ms (between participants), and were followed by the binocular presentation of a fixation for 500 ms. Finally, a target number was binocularly presented until the microphone registered a voice response (see Fig. 1).

Immediately after the completion of the two tasks a forced-choice objective test was administered (Cheesman & Merikle, 1984; Merikle & Reingold, 1992). Participants completed 64 trials, in which the presentation parameters were identical to the experimental trials. Participants were informed of the existence of primes, and their task was to report the parity of the first digit in the masked equations. After participants completed the objective test they were debriefed and directly asked whether they had seen the primes during the experimental blocks.

Results

Awareness tests.

We used the binomial distribution to determine whether each participant performed better than chance on the objective block, and excluded from analyses all those who did (8, 10 and 11 in the 1400 ms, 1700 ms and 2000 ms presentation duration conditions respectively). Note, that while the number of excluded participants may seem high, they fall within the normal range of long-duration CFS priming (e.g. Bahrami et al 2010; Yang, Hong & Blake, 2010). We additionally excluded participants who reported awareness of the prime equations in the debriefing (3, 2 and 2, respectively). For the remaining participants, objective test scores did not differ from chance (M=0.503, SE=0.073), $t(25)=0.21$, $p=0.832$.

Non-conscious Arithmetic.

A 3 (Prime Duration: 1400 ms, 1700 ms or 2000 ms; between subjects) X 2 (Operand: Addition vs. Subtraction) X 2 (Prime-target Congruence: Congruent vs. Incongruent) mixed ANOVA of reaction times (RT) to correct responses revealed a significant two-way interaction of Congruence and Operand, $F(1,23)=9.37$, $p=0.006$, qualified by a significant three-way interaction of Congruence, Duration and Operand,

$F(2,23)=3.64$, $p=0.042$ (see Fig. 2a, 2b). The same analysis for accuracy did not yield significant effects and will not be discussed further.

We therefore preformed separate 2 (Congruence) X 3 (Duration) ANOVAs for the addition and subtraction conditions. We begin with the more difficult equation, the subtraction. A significant main effect of Congruence was found, $F(1,23)=14.24$, $p=0.001$, as well as marginal interaction of Congruence by Duration, $F(2,23)=3.21$, $p=0.059$. These results indicate that subtraction equations were solved even though participants were unaware of them. As seen in Figure 2a, this effect was not yet apparent at 1400ms, it was strongest at 1700ms, and it somewhat diminished at 2000ms, $t(8)=0.43$, $p=0.68$; $t(7)=3.27$, $p=0.014$, and $t(8)=2.13$, $p=0.066$, respectively. Surprisingly, there was no effect of priming for addition, a finding we return to in Experiments 2 & 3.

This pattern of results suggests two conclusions. First, arithmetic equations *can* be solved unconsciously. Second, even the non-conscious solution of arithmetic equations requires time.

Experiment 2

One could argue that the results of the first experiment reflect estimation rather than solution (e.g., "5+4+1 is somewhere between 8 and 11"). In the current experiment we therefore systematically varied the distance between the targets and the primes. Specifically, targets were either *identical* to the primed solutions (e.g., 9-5-1= followed by 3), *close* to the solutions (distance between prime and target ranged from 1 to 2) or *far* from them (distance ranged from 3 to 4; see table S2 in the supporting information available on-line for a complete list). Previous research has established that numbers are represented on a form of a number line, such that each number is associated with its near neighbors more than with its far neighbors (Den Heyer & Briand, 1986; Reynvoet & Brysbaert,1999). If participants solve the equations, we expect to find an effect of prime-target distance, with shortest RTs in the *identity* condition, intermediate RTs in the *close* condition, and longest RTs in the *far* condition.

Method

Participants and design.

29 (16 female) Hebrew university students (M_{age}=22.9, SD=2.53) participated in the experiment. They were randomly allocated to the conditions of a 2 (Operand: Addition vs. Subtraction) x 3 (Distance: Identity vs. Close vs. Far) within subject design.

Stimuli.

64 addition equations and 48 subtraction equations were used. Each equation was matched with one congruent and one incongruent target, and each equation was presented only once (counterbalanced between participants). Fifty percent of the primes were congruent (*identical* condition) and 50% were incongruent. [25 % in the *close* incongruent condition (prime-target distance equaled one for subtraction and two for addition) and 25% in the *far* incongruent condition (prime-target distance equaled three for subtraction and four for addition)].

Procedure.

The procedure was identical to that of Experiment 1, with the exception of presentation duration which was fixed at 1700ms. The parameters of the objective test were identical to Experiment 1, but for generality purposes the judgment task was varied. In the current experiment half of the equations presented in the objective test were comprised of three numbers (identical to those used in the experiment), and the other half were comprised of three random Latin letters (e.g., A+B+C =). Participants' task was to indicate whether the presented equation was comprised of letters or numbers.

Results

Awareness tests.

We used the same exclusion criteria as those of Experiment 1. 16 participants were excluded based on the objective test and 3 additional participants were excluded based on their subjective report. For the remaining participants, the objective test score did not differ from chance (M=0.518, SE=0.07), $t(9)=0.81$, $p=0.438$.

Non-conscious Arithmetic.

First, replicating the results of Experiment 1, a 2 (Congruence: Congruent vs. Incongruent) X 2 (Operand: Addition vs. Subtraction) ANOVA of RTs to correct responses revealed a significant interaction, $F(1,9)=5.53$, $p=0.043$. We therefore report separate ANOVAs for addition and subtraction. Participants did not make any naming errors in this experiment, so accuracy was not analyzed.

Beginning again with the difficult equations, subtraction, a one-way ANOVA of RTs to correct responses found a significant effect of distance, $F(2,18)=4.62$, $p=0.024$, as well as a significant linear contrast, $F(1,9)=6.79$, $p=0.028$. RTs were shortest in the *identical* condition, intermediate in the *close* condition and longest in the *far* condition (M=581.07 ms, SE=23.79; M=590.2 ms, SE=25.98, and M=604.11 ms, SE= 28.76 respectively; see Fig. 3). These results demonstrate again that in the current paradigm subtraction equations are solved even when they are presented subliminally. Furthermore, the distance effect suggests that the solutions were concrete numbers and not ballpark estimations.

Like in Experiment 1, there was no evidence to the solution of addition equations. One possible explanation for this difference is that magnitude matters: The solutions for the addition equations were larger than those for subtraction, and hence, maybe, more difficult to compute. To examine this possibility we divided the addition equations into high vs. low solutions (we did two sets of analyses of this sort: in one we used a single- vs. two digit criterion, and in the other we used a median split). The various comparisons between these conditions yielded no significant differences, all ps>0.17. These results suggest that the magnitude of the solution did not play a big role here. We turn to another possible explanation in Experiment 3.

Experiment 3

The puzzle that this experiment addresses is the lack of evidence for the solution of addition equations, where there is strong and consistent evidence for the non-conscious solution of the more difficult subtraction equations.

Recall that the results of the pilot showed that participants were faster to solve addition than subtraction (in three digit equations). Given that the temporal presentation parameters were identical for both operands, this suggests that the time that elapsed between the non-conscious solution of the equation and the appearance of a target, was longer for addition. Hence, addition solutions have had more time to decay, thereby leading to null effects. This possible explanation seems probable in light of the rapid rise and decay evidenced in Experiment 1 (see Fig. 2a).

In Experiment 3, then, we examine addition with shorter presentation durations. We also use a new paradigm which stresses accuracy instead of reaction time as the primary dependent measure, thus allowing a generalization of the previous findings. To achieve the first goal we reduced the inter stimulus interval from 1900-2500 milliseconds in Experiments 1 and 2 (Fig. 1) to only 1000 ms. To achieve the second goal, we changed the task from naming target numbers, to judging whether arithmetic statements were correct. Thus, for example, after having been subliminally primed with 3+4 = , participants were supraliminally exposed to 2+5=7, and were asked to indicate, using a key press, whether the latter is correct. As in Experiment 1, the results of the primes were either *identical* to the targets (e.g. 5+3 = followed by 6+2=8) or not (e.g. 5+3= followed 7+4=11).

Due to target complexity considerations (see stimuli choice criteria in Experiment 1), it was not feasible to use three-digit equations. Hence, the equations used two single-digit equations (see table S3 in the supporting information available on-line for a complete list). These equations are easier than those used in Experiment 1 and 2. Yet, for the current purposes it is important to keep in mind that the more difficult subtraction equations were solved in both previous experiments, hence difficulty is unlikely to be the crucial factor here.

Method

Participants and design.

56 (43 female) Hebrew university students (M_{age}=23.14, SD=3.5) participated in the experiment. There was one within participant factor (Congruence: Congruent Vs. Incongruent).

Stimuli and Procedure.

24 two-digit addition equations were used in the experiment. Each equation was presented twice with a congruent equation and twice with an incongruent equation.

The experimental setting was similar to the one used in the previous experiments. Participants completed 192 experimental trials. On 96 (50%) of the trials the explicit target was correct (e.g. 3+4=7), and on the remaining trials it was incorrect (e.g. 4+6=13); the data of the latter trials were not analyzed. Participants were asked to indicate the target's correctness by pressing one of two keys on the keyboard ("/" for correct and "z" for incorrect). Each target equation was preceded by a prime equation presented for 800 ms, and a fixation cross which was presented for 200 ms.

Upon completing the experiment participants completed an objective test block (48 trials), which was identical to that of Experiment 1 with one modification: Participants were asked to judge the parity of the last digit in the equation, instead of the parity of the first one.

Results

Awareness tests.

Seven participants performed better than chance on the objective block (see Experiments 1 for the estimation process), and three additional participants indicated subjective awareness. All of them were excluded from analyses. Also excluded was one participant who did not follow the experimental instructions. Objective test scores of the remaining participants did not differ from chance, M=0.499, SD=0.057, t_{45}=-0.16, p=0.872.

Non-Conscious Arithmetic.

Accuracy. 12 participants who did not make any mistake in the incongruent condition (i.e., they were at ceiling), and therefore could not have shown improvement in the congruent condition, were excluded from analyses.

Supporting our hypothesis, participants made less mistakes in the congruent condition than in the incongruent condition (M=3.2%, SE=0.6 and M=4.4%, SE=0.4 respectively), $t(32)=2.13$, $p=0.041$.

Reaction times. Participants in the incongruent condition (M=1240.41 ms, SE=71.41) seemed to be faster than participants in the congruent condition (M=1272.5 ms, SE=74.89), $t(32)=1.81$, $p=0.08$. This marginal effect may suggest that the presentation of non-conscious equations may lead to strategic changes in behavior. Yet, this trend was not hypothesized, so we do not wish to make much of it.

To summarize, then, the current results demonstrated that addition equation can be solved non-consciously, and suggest that, as hypothesized above, the solution to addition equations decayed in Experiment 1 and 2.

General Discussion

Making use of an innovative technique, CFS, arithmetic equations were presented subliminally, yet for a durations that ranged from 800 milliseconds to two seconds. Evidence from objective blocks and subjective measures was used to verify subliminality. Data from unaware participants in 3 experiments unequivocally show that arithmetic computations can be carried out without awareness.

Surprisingly, the first two experiments suggested that more difficult arithmetic computations (subtraction) can be carried out unconsciously, whereas easier computations are not. Based on the pilot data we suggested that duration plays an important role here. And indeed, when presentation duration was significantly reduced, in Experiment 3, evidence for non-conscious solution of addition equations emerged. Experiment 3 has another advantage: it uses a slight variation on the paradigm used in the first two experiments, hence allowing a generalization of the results.

Crucially, the hypothesis that motivated this research was that rule-based computations that use abstract and symbolic representations can occur non-consciously. The current findings provide strong support for this hypothesis. They therefore suggest that the modal view of the division of labor between conscious and unconscious processes should be significantly updated. This updating opens the way for further discoveries about the capacities of the unconscious, which should, in turn, reflect on our understanding of the functions of consciousness.

References

Abrams, R. L., & Greenwald, A. G. (2000). Parts outweigh the whole (word) in unconscious analysis of meaning. *Psychological Science*, *11*, 118–124.

Ashcraft, M. H. (1992). Cognitive arithmetic: A review of data and theory. *Cognition*, *44*, 75–106.

Ashcraft, M. H. (1995). Cognitive psychology and simple arithmetic: A review and summary of new directions. *Mathematical Cognition*, *1*, 3-34.

Bahrami B., Vetter P., Spolaore E., Pagano S., Butterworth B., & Rees G. (2010). Unconscious numerical priming despite interocular suppression. *Psychological Science*, *21*, 224-233.

Bargh, J. A. (Ed.). (2007). *Social psychology and the unconscious: The automaticity of higher mental processes*. New York: Psychology Press.

Bargh, J. A., & Chartrand, T. L. (2000). The mind in the middle: A practical guide to priming and automaticity research. In H. T. Reis & C. M. Judd (Eds.), *Handbook of research methods in social and personality psychology* (pp. 253–285). New York: Cambridge University Press.

Baumeister, R. F., & Masicampo, E. J. (2010). Conscious thought is for facilitating social and cultural interactions: How simulations serve the animal-culture interface. *Psychological Review*, *117*, 945-971.

Cheesman, J., & Merikle, P. M. (1984). Priming with and without awareness. *Perception and Psychophysics*, *36*, 387–395.

Damian, M. F. (2001). Congruity effects evoked by subliminally presented primes: Automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 154–165.

Dehaene, S., Naccache, L., Le Clec, H. G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P. F., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature*, *395*, 597–600.

Den Heyer, K., & Briand, K. (1986). Priming single digit numbers: Automatic spreading activation dissipates as a function of semantic distance. *American Journal of Psychology*, *99*, 315-340.

Deutsch, R., Gawronski, B., & Strack, F. (2006). At the boundaries of automaticity: Negation as reflective operation. *Journal of Personality and Social Psychology*, *91*, 385–405.

Dijksterhuis, A. (2004). Think different: The merits of unconscious thought in preference development and decision making. *Journal of Personality and Social Psychology*, *87*, 586–598.

Dijksterhuis, A., & Aarts, H. (2010). Goals, attention, and (Un)Consciousness. *Annual Review of Psychology, 16,* 467-490.

Dijksterhuis, A., Bos, M. W., Nordgren, L. F., & van Baaren, R. B. (2006). On making the right choice: the deliberation-without-attention effect. *Science*, *311*, 1005–1007.

Evans, J. (2008). Dual-processzing accounts of reasoning, judgment, and social cognition. *Annual Review of Psychology*, *59*, 255-278.

Galfano, G., Rusconi, E., & Umiltà, C. (2003). Automatic activation of multiplication facts: Evidence from the nodes adjacent to the product. *Quarterly Journal of Experimental Psychology*, *56*, 31-61.

Garcia-Orza, J., Damas-López, J., Matas, A., & Rodriguez. J. M. (2009). " 2 x 3" primes naming" 6": Evidence from masked priming. *Attention, perception & psychophysics*, *71*, 471-480.

García-Orza, J., & Perea, M. (2011). Position coding in two-digit Arabic numbers: Evidence from number decision and same-different tasks. *Experimental Psychology*, *58*, 85-91.

Greenwald, A. G. (1992). New Look 2: Unconscious cognition reclaimed. *American Psychologist 47*, 766-779.

Greenwald, A. G., Abrams, R. L., Naccache, L., & Dehaene, S. (2003). Long-term semantic memory versus contextual memory in unconscious number processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 235–247.

Greenwald, A. G., & Liu, T. J. (1985). *Limited unconscious processing of meaning*. Presented at annual meeting of the Psychonomic Society, Boston.

Hassin, R. R., Uleman, J. S., & Bargh, J. A. (Eds). (2005). *The new unconscious*. Oxford: Oxford University Press.

Jackson, N. D., & Coney, J. R. (2005). Simple arithmetic processing: The question of automaticity. *Acta Psychologica*, *119*, 41-66.

Kouider, S., Dehaene, S. (2007). Levels of processing during non-conscious perception: a critical review of visual masking. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*, 857-875.

Kouider, S., & Dehaene, S. (2009). Subliminal number priming within and across the visual and auditory modalities. *Experimental Psychology*, *56*, 418–433.

Merikle, P. M., & Reingold, E. M. (1992). Measuring unconscious perceptual processes. In R.F. Bornstein & T.S. Pitman (Eds.), *Perception without awareness: Cognitive, clinical, and social perspectives* (pp. 55–80). New York: Guilford Press.

Morewedge, C. K., & Kahneman, D. (2010). Associative processes in intuitive judgment. *Trends in Cognitive Sciences*, *14*, 435–440.

Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition*, *80*, 223–237.

Reynvoet, B., & Brysbaert, M. (1999). Single-digit and two-digit Arabic numerals address the same semantic number line. *Cognition*, *72*, 191–201.

Tsuchiya, N., & Koch, C. (2005). Continuous flash suppression reduces negative afterimages. *Nature Neuroscience*, *8*, 1096–1101.

Van den Bussche, E., Van den Noortgate, W., & Reynvoet, B. (2009). Mechanisms of masked priming: A meta-analysis. *Psychological Bulletin*, *135*, 452–477.

Winkielman, P.W., & Schooler, J.W. (2009). Unconscious, conscious, and metaconscious in social cognition. In F. Strack & J. Forster (Eds.), *Social cognition: The basis of human interaction* (pp. 49-69). Philadelphia: Psychology Press.

Yang, E., Hong, S. W., & Blake R. (2010). Adaptation aftereffects to facial expressions suppressed from visual awareness. *Vision*, *10*, 1-13.

Zbrodoff, N. J., & Logan, G. D. (1986). On the autonomy of mental processes: A case study of arithmetic. *Journal of Experimental Psychology: General*, *115*, 118 –130.

Figure Captions

Figure 1

Order and duration of stimuli presentation in Experiments 1 and 2. Dynamic masks were comprised of 3 rows of 7 random Hebrew letters, forming no coherent words, that changed at a rate of 10 hz. Equations contrast was gradually ramped up in 5 steps during the first 500 milliseconds of each trial up to 50% contrast.

Figure 2

RT facilitation scores (incongruent– congruent) for the 3 between participant conditions of Experiment 1, as well as Experiment 2 (a. subtraction; b. addition). Error bars denote standard error (s.e.).

Figure 3

Average RTs for *identical* congruent subtraction (prime-target distance equals 0); *close* incongruent subtraction (prime-target distance equals 1), and *far* incongruent subtraction (prime target distance equals 3) in experiment 2. Error bars denote standard error (s.e.).

Figure 1

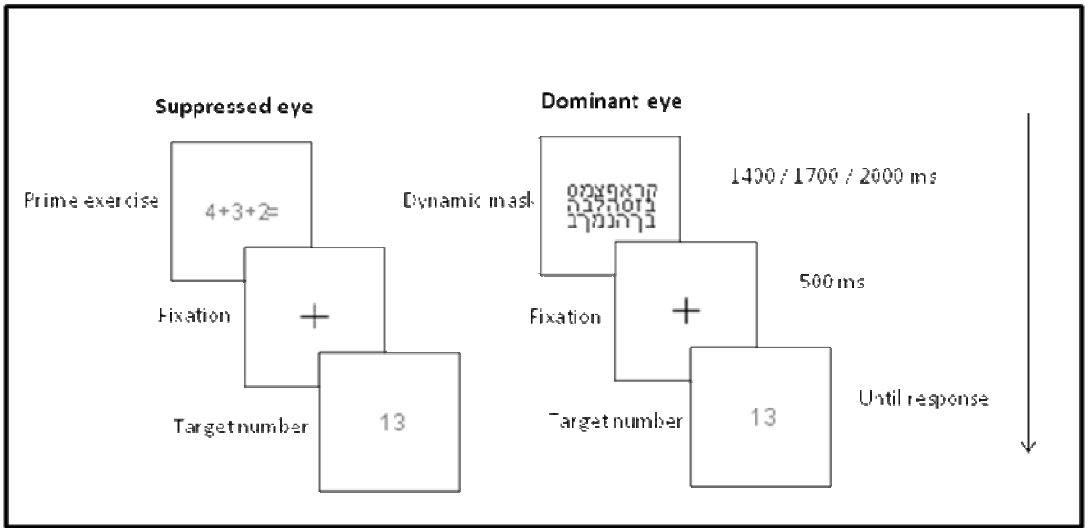
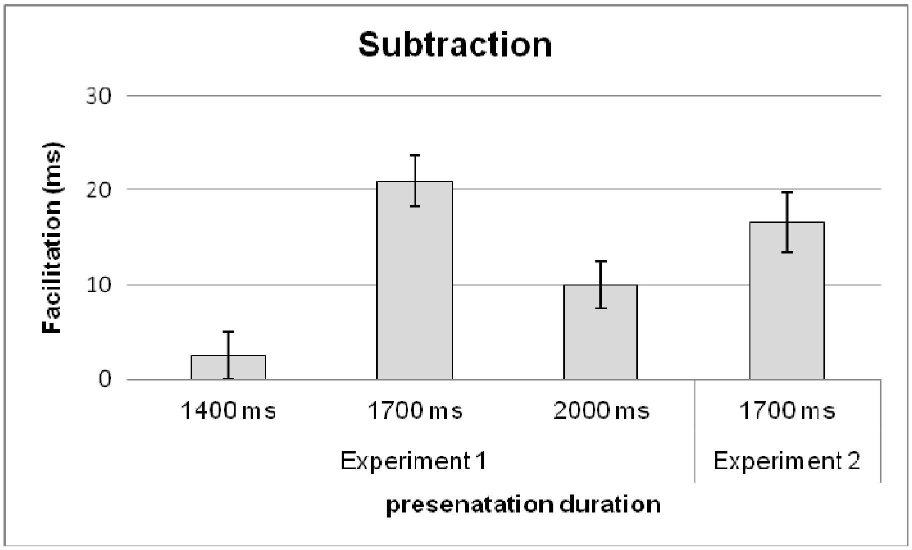

Suppressed eye
Dominant eye
Prime exercise
4+3+2=
Dynamic mask
1400 / 1700 / 2000 ms
Fixation
Fixation
500 ms
Target number
13
Target number
13
Until response

Figure 2

a.


Subtraction
30
20
10
0
Facilitation (ms)
1400 ms
1700 ms
2000 ms
1700 ms
Experiment 1
Experiment 2
presenatation duration

b.

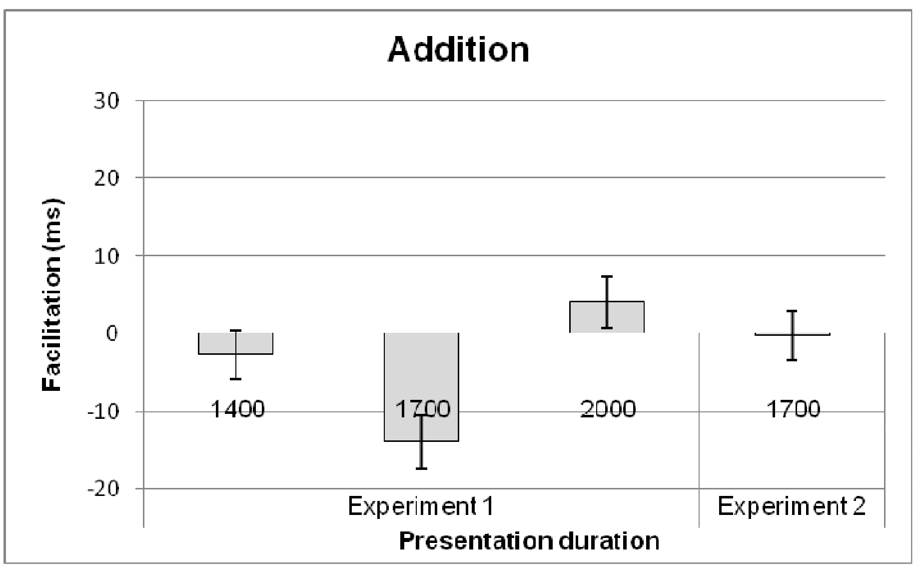
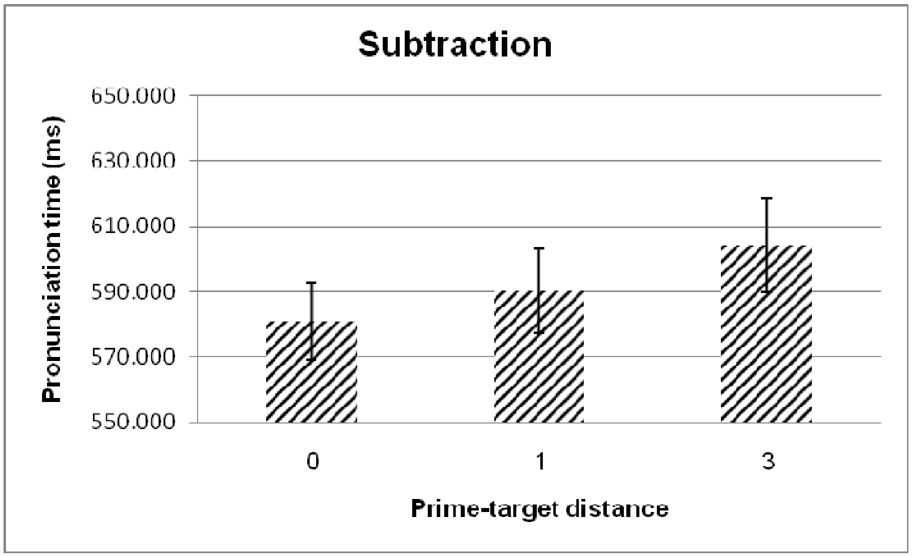

Addition
30
20
10
0
-10
-20
Facilitation (ms)
1400
1700
2000
1700
Experiment 1
Experiment 2
Presentation duration

Figure 3


Subtraction
650.000
630.000
610.000
590.000
570.000
550.000
Pronunciation time (ms)
0
1
3
Prime-target distance